Variometer Prototype

2009-01-29

Apart from lash-ups with inductors on the bench I've never built a permanent, mechanically robust Variometer before. It has been a long-time interest though, both as a bench variable inductance tool and for practical uses in RF circuits - especially antenna matching.

The Variometer relies on varying the mutual inductance between two coaxial solenoid inductors. This allows an inductance range of 4 times the mutual inductance, generally resulting in a 2:1 range of inductance/reactance for the finished device. The coupling of the inductors is varied by rotating one of the inductors with respect to the other. Rotation through a complete 180 degrees allows mutual inductance sign reverse (phase inversion) giving the full 4 times the mutual inductance range, as Ltotal = L1 + L2 + 2*Lm. Uncoupled, the inductors in series would total just L1 + L2 as per normal circuit theory, but their mutual coupling gives rise to the Lm term. Lm can be negative if the magnetic coupling is anti-phase, which like a capacitance can cancel the normally additive inductance.

I started construction by drawing a sketch and doing the maths to determine the geometrical limits on the inner inductor to allow rotation within the outer one. If the ID of the outer coil form is "D", the OD of the inner coil (coil + form) is "d", and the height of the inner coil form is "l", then this inequality must be met to allow rotation: d^2 + l^2 < D^2, which implies the inner former length can't exceed sqrt(D^2 - d^2). Similarly, if you want the inner coil to not poke out past the ends of the outer former (so it can be end-mounted for example), then the height "h" of the outer former must satisfy: h^2 > d^2 + l^2.

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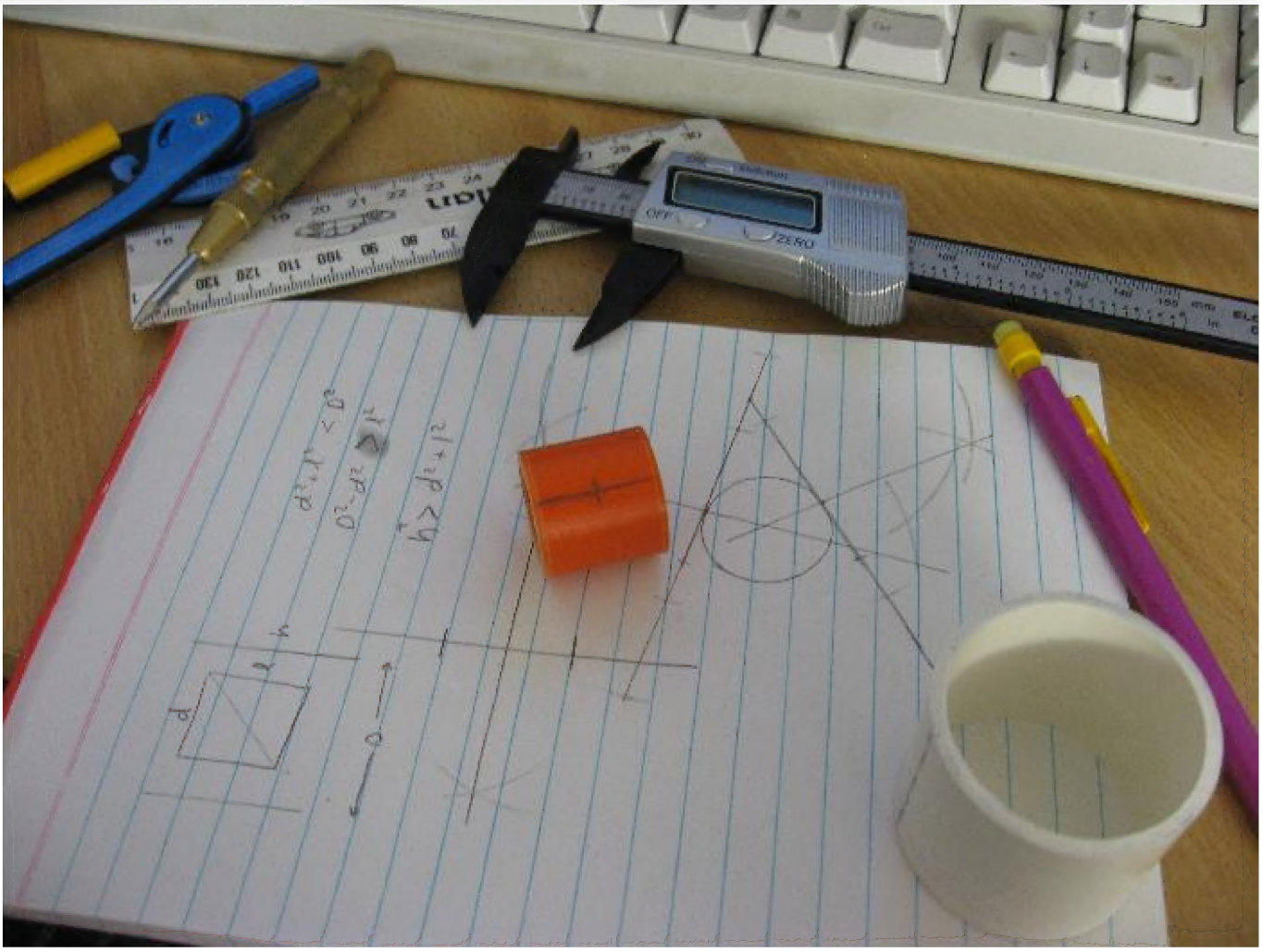

Some 25 mm PVC conduit was selected for the inner coil form, along with 38 mm ID PVC water pipe this constrained the inner coil form hight to be less than 28 mm, I chose 25 mm to give it a little bit of play. The "square" inner coil form constrained the outer coil form height to exceed 36 mm for bench-mountable niceness, so I picked 38 mm and cut up the tubes with a pipe cutter. Some rather inelegant geometrical constructions later to find the centres of the tube walls in both directions and the pipes were drilled.

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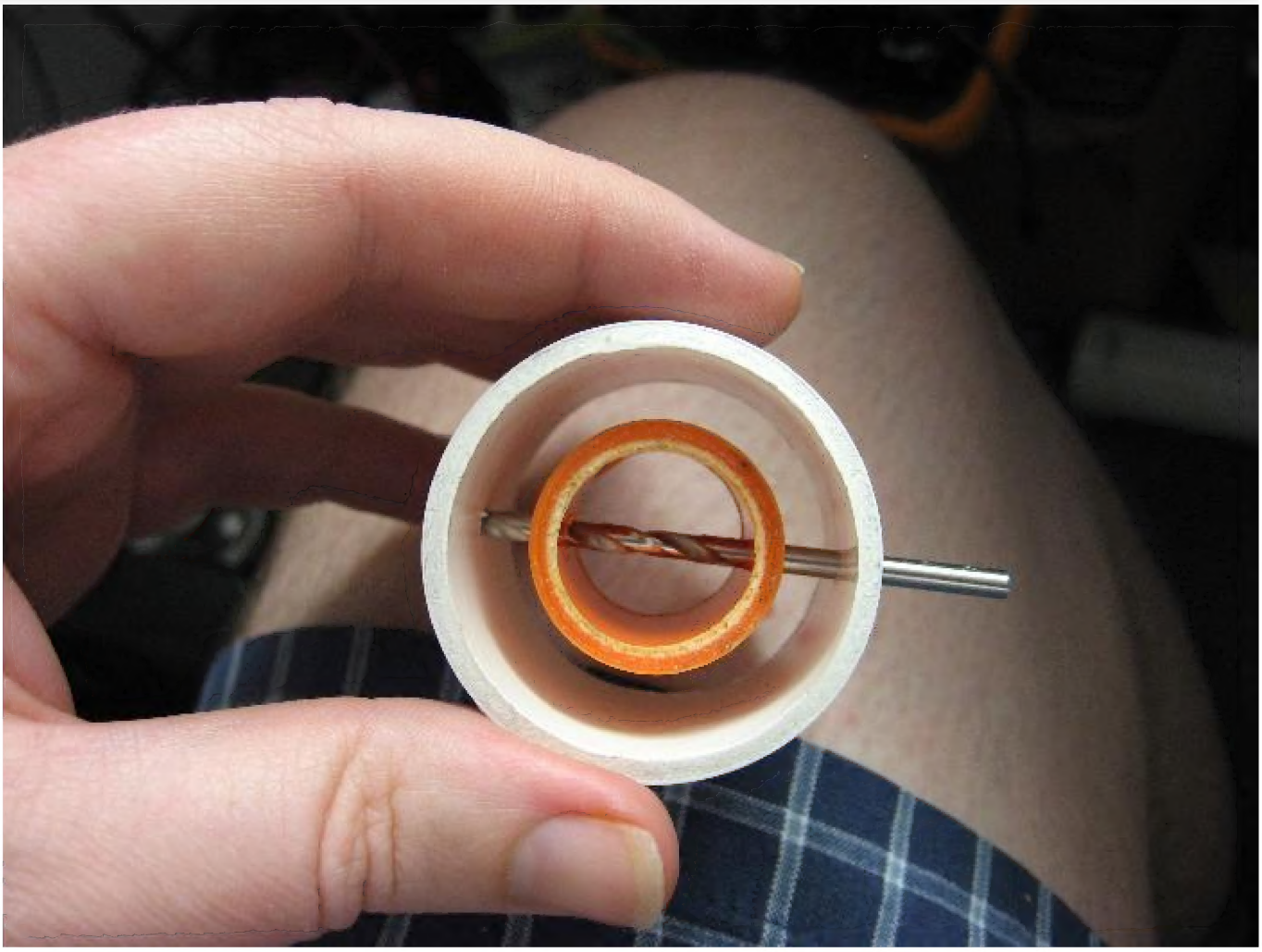

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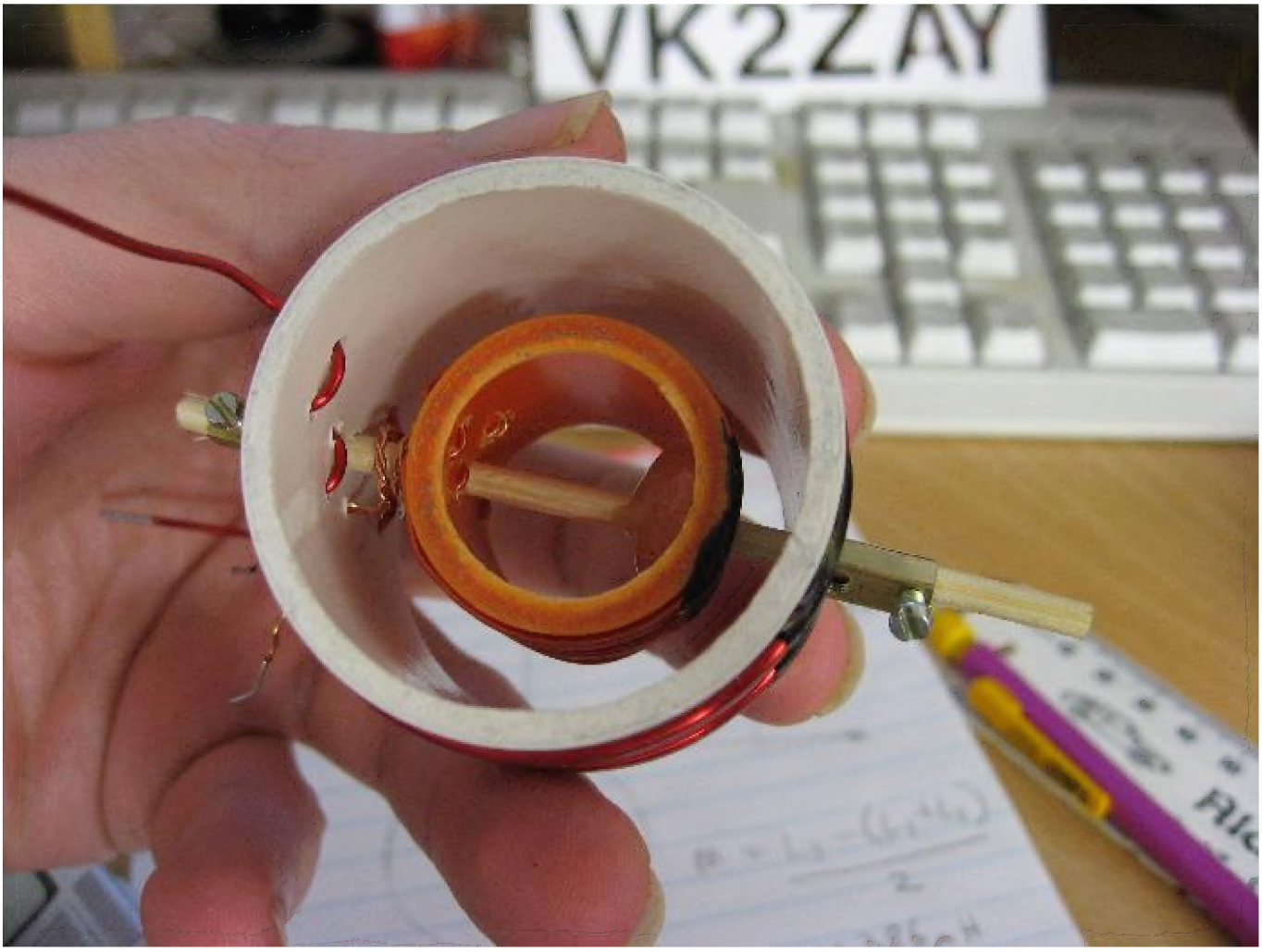
Some 1.3 mm holes were drilled for securing the coil turns and the coils wound. 710 um wire was used for the inner coil, 12 turns total, 6 either side of the rotation axle. For the outer coil 5 turns each side for a total of 10 with 1 mm wire. Some liquid electrical tape was used to hold the windings of both coils in place. Some twisted-pair of 500 um wire coiled around the axle brought out the inner coil connections in a flexible manner (but I have my doubts about the long-term robustness of this arrangement, multi-strand wire would be better where the flexing occurs). The axle was formed by a 3 mm bamboo kebab stick. After trial assembly the rotor was fixed to the axle with hot-melt glue and the centring assured using brass chocolate-bar connector inserts secured over the axle as it exits the outer coil form.



The outer coil measures 4.473 uH. The inner 3.127 uH. In phase they total 10.371 uH and anti-phase 4.869 uH. The matching mutual inductance Lm = [Ltotal - (L1 + L2)] / 2 is 1.386 uH. The coupling coefficient k = Lm/sqrt(L1*L2) is 0.371. The measured "range" of 5.5 uH closely agrees with the theoretical 4*Lm figure of 5.542 uH. I was also surprised by the extremely good agreement of the measured figures with the calculator on this excellent variometer page. If you punch in the geometry of my device the figures it outputs are very close indeed, within a few percent. It seems to slightly over-estimate the Lm, but not enough to be a problem in practice.

This "5-10 uH" variable inductor might become my long desired "L-jig" to match the other R and C ones, or it might become the interpolating inductor along with a fixed taped inductor in an L network matching unit. It's unfortunately high 5 uH inductance limits the HF response of such a matcher, having about j943 Ohms impedance at 30 MHz, however this could be tuned-out with a series capacitor capable of tuning below 5.6 pF. Designing a tapped inductor with ~ 10 uH steps for 90-100 uH would let me tune a 23 pF vertical at minimum of 80 metres. I know the 3 metre vertical on my balcony takes less than 60 uH to tune it (ie 32-33 pF of capacitance), so even just a 50 uH fixed inductor tapped 5 times plus this inductor could tune out its capacitance across HF as long as I had a way to switch in a series variable capacitance on the last tap (Variometer only).

7 comments.

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